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# RESEARCH MEMORANDUM

## SOME EFFECTS OF FIN LEADING-EDGE SHAPE ON AERODYNAMIC HEATING AT MACH NUMBER 2.0 AT A STAGNATION TEMPERATURE OF ABOUT 2,600° R

By William M. Bland, Jr.

Langley Aeronautical Laboratory
Langley Field, Va.



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# SOME EFFECTS OF FIN LEADING-EDGE SHAPE ON AERODYNAMIC HEATING AT MACH NUMBER 2.0 AT A STAGNATION TEMPERATURE OF ABOUT 2,600° R

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## SUMMARY

Three uninstrumented tapered magnesium fins with the leading edges swept back 17° have been tested in an ethylene-heated high-temperature jet of the Langley Pilotless Aircraft Research Station at Wallops Island, Va. These tests were made to investigate some effects of leading-edge diameter and leading-edge shape on the aerodynamic heating by noting the time for melting to begin on the fins. Results of these tests, which were conducted at a Mach number of 2.0 for stagnation temperatures in the neighborhood of 2,600° R, indicate that increasing the diameter of the cylindrical leading edge increased the time required for melting to start. This increase was greater, probably because of conduction effects, than that predicted by relating the time to melt inversely with the square root of leading-edge diameter. Also, the model with the flat-face leading edge lasted 1.39 times as long as the model with about the same size cylindrical leading edge.

## INTRODUCTION

At high Mach numbers aerodynamic heating becomes severe, particularly along the leading edges of fins and wings and the forward parts of bodies. It is possible that the rate of heat input to fin leading edges can limit the duration of a flight by increasing the temperature of the material in the fin structure past the safe limits. In fact, the loss of some rocket-propelled hypersonic research models, as discussed in reference 1, has been attributed to failure of the stabilizing fins caused by excessive aerodynamic heating.

Several ways of alleviating the aerodynamic-heating effects are available. One way is to insulate the basic load-carrying structure with protective coverings (refs. 1 to 3). Another way is to reduce the heat transferred from the airstream to the structure by changing the geometry of the fin. Increasing the sweepback of the fin leading edge has been shown by analysis and by experiment in references 4 to 6 to decrease the average aerodynamic heat-transfer coefficient at the leading edge. It has also been shown in these references and elsewhere that the average aerodynamic heat-transfer coefficient for a cylindrically shaped leading edge is inversely proportional to the square root of the leading-edge diameter. Thus, an increase in leading-edge diameter results in a decrease in aerodynamic heat-transfer coefficient and an increase in heat capacity at the leading edge. The aerodynamic heat transferred to flat-face cylinders has been shown in reference 7 to be less than that transferred to hemisphere-tipped cylinders. A similar decrease in aerodynamic heating is expected for the two-dimensional case when a cylindrical leading edge is replaced by a flat leading edge.

A limited investigation of the effects of leading-edge diameter on the magnitude of the aerodynamic heating has been conducted in the ethylene-heated high-temperature jet of the Langley Pilotless Aircraft Research Station at Wallops Island, Va. The tests were conducted by exposing three uninstrumented models with different leading edges to a Mach number 2.0 airstream with stagnation temperatures in the neighborhood of 2,600° R.

## MODELS

The models used in this investigation were tapered fins with the leading edges swept back 17° and a half-wedge angle of 5.5° at the leading edge. (See fig. 1.) The models were made from portions of magnesium castings that were identical with those used as the leading edges of fins that stabilize early stages of rocket-propelled hypersonic research models. These models were also similar to the magnesium leading edges of the models of reference 2.

Model 1 had a cylindrical leading edge with a diameter of 1/8 inch. Model 2 was similar to model 1 except that the leading edge was cut back until it was flat and 1/8 of an inch wide. Model 3 was also similar to model 1 except that the cylindrical leading edge was cut back until a new cylindrical leading edge 3/8 of an inch in diameter was formed. It is estimated that the leading-edge dimensions are known within ±0.005 inch. Surface roughness is estimated to have been of the order of 100 to 125 microinches. The models were not instrumented.

## TEST PROCEDURE

The investigation was conducted by exposing the models at an angle of attack of $0^{\circ}$ to a Mach number 2.0 airstream in the 12-inch-diameter ethylene-heated high-temperature jet of the Langley Pilotless Aircraft Research Station at Wallops Island, Va. Each model was mounted on a stand that would insert the model into the jet once the desired flow conditions had been established. The models were withdrawn from the jet as soon as possible after the first damage was observed. The motion of the stand was such that a model traversed about one-half the jet stream in about 0.4 second while being rotated to the test position at the jet center line and while being withdrawn.

Motion pictures of a model and an electric clock were taken from one side and from overhead at approximately 128 frames per second during each test. The films provide the only source of data from these tests other than jet operating conditions. From these films were obtained the time at which leading-edge damage was first observed after the model reached the testing position and also the total time in the testing position.

A more detailed description of the operation and characteristics of the ethylene-heated high-temperature jet is presented in reference 1.

## TESTS AND DISCUSSION

The temperature varied across the diameter of the jet during the tests, the maximum temperatures occurring near the center line, as discussed in reference 1. Calculated stream conditions based upon the center-line temperature immediately upstream of the model are presented in figure 2. The three models were to be tested at a stream stagnation temperature of $2,500^{\circ}$ R; however, control over the temperature was not exact and the stagnation temperatures varied as shown in figure 3.

The jet was operated so that the stream static pressure at the jet exit was 0.78 times the ambient atmospheric pressure. This condition resulted in a total pressure of 9,780 pounds per square foot immediately downstream of the detached shock waves which formed ahead of the $17^{\circ}$ sweptback leading edges of the models. Since the jet pressure was less than ambient pressure, shock diamonds were formed near the exit and extended downstream to intersect on the jet center line about 2 inches behind the leading edges of the models.

The models were withdrawn from the jet as soon as the first damage to them was observed. Model 1 is shown in the testing position in figure 4. Resulting damage to the models after exposure in the jet at the stagnation temperatures presented in figure 3 is shown in figure 5 for the noted exposure times.

Observations made with the slow-motion movie films show that the initial surface melting of the magnesium occurred at the leading edge of each model near the jet center line. Selected frames from the motion-picture films of each test have been enlarged and are presented in figure 6. First melting was observed in 1.65 seconds for model 1, 2.30 seconds for model 2, and 4.08 seconds for model 3 after the testing position was attained. Extent of the damage to each fin 0.5 second after melting was first observed can be seen in the test pictures at the bottom of each column in figure 6.

Theoretically, the aerodynamic heat transfer to cylindrical leading edges varies inversely as the square root of the leading-edge diameter. Also, the time for melting to occur on fins made of the same material is inversely related to the heat transferred to the fin. Therefore, it can be stated that for given test conditions the ratio of the times for melting to occur at the leading edges of two models can be expected to be proportionally related to the square root of the ratio of the leading-edge diameters except for modifications necessary to account for differences in heat capacity and conduction.

Application of the relation between time to melt and the leading-edge diameter results in a prediction that model 3 with three times the leading-edge diameter of model 1 would last 1.73 times as long as model 1 before starting to melt. The test results exceeded this prediction by showing that model 3 lasted 2.48 times as long as model 1 before starting to melt. The difference between predicted and measured results could have been caused by the greater heat capacity and heat conduction capabilities of the leading edge of model 3 and also by the somewhat more severe test conditions imposed upon model 1.

A comparison of the test results obtained for model 1 and model 2, which had leading edges of about the same size, showed that the model with the flat-face leading edge lasted 1.39 times as long as the model with the cylindrical leading edge. The slightly more severe test conditions imposed upon model 1 probably account for only a small part of the difference in the time for melting to start.

Applying the relation between the time to melt and the leading-edge diameter makes it possible to estimate that a model with a cylindrical leading edge would have required a leading-edge diameter almost twice the width of the flat face to last as long as the flat-face leading-edge model.

## CONCLUDING REMARKS

Three magnesium fins, two with cylindrical leading edges and one with a flat-face leading edge of about the same size as the smallest cylindrical leading edge, have been tested in an ethylene-heated high-temperature jet at a Mach number of 2.0. Results of these tests, which were made at stagnation temperatures in the neighborhood of 2,600° R, indicate that increasing the diameter of cylindrical leading edge increased the time required for melting to start. This increase was greater, probably because of conduction effects, than that predicted by relating the time to melt inversely with the square root of the leading-edge diameter. The results also indicated that a model with a flat-face leading edge lasted 1.39 times as long, before melting started, as a model with almost the same size cylindrical leading edge.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., Oct. 18, 1957.

## REFERENCES


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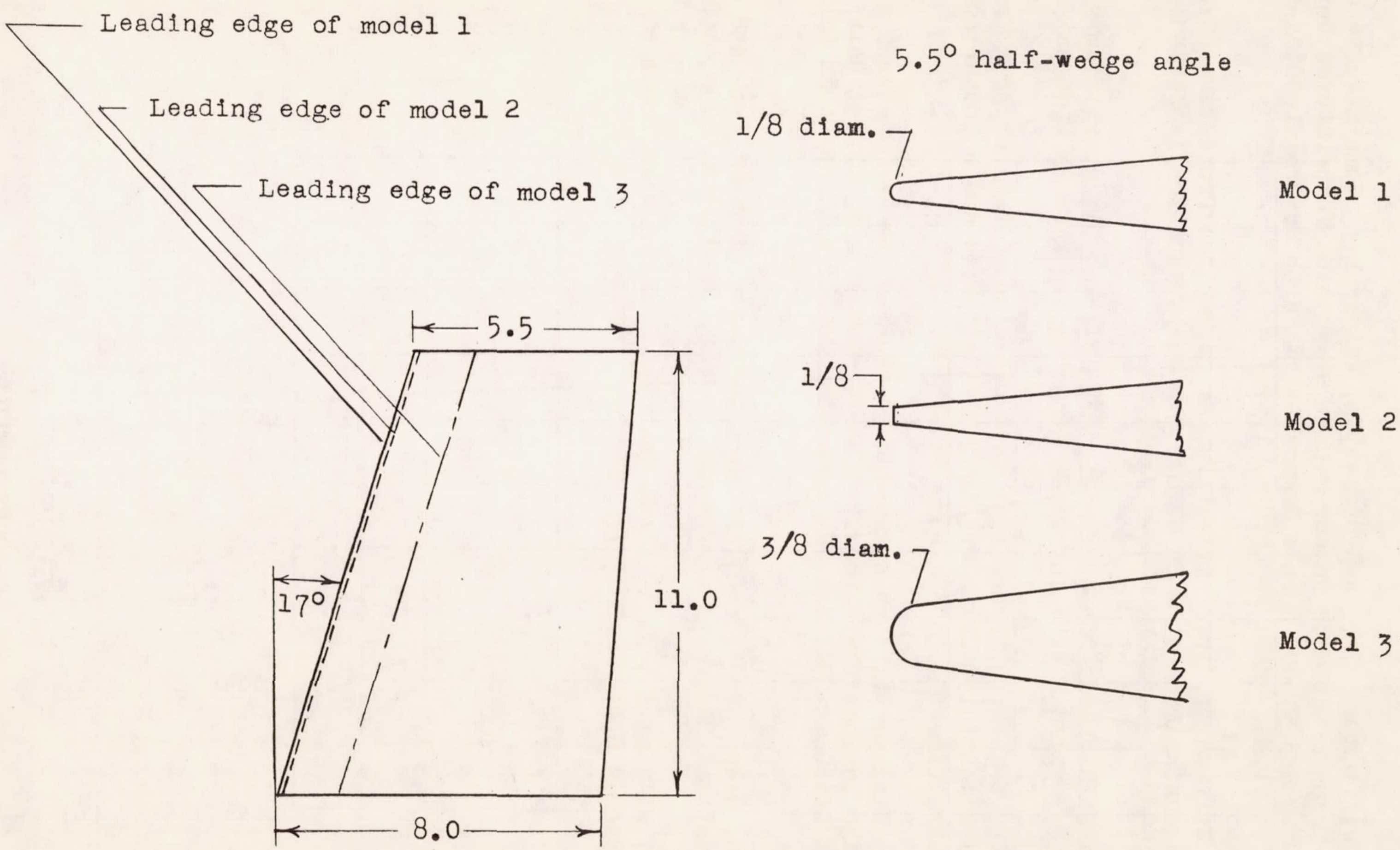
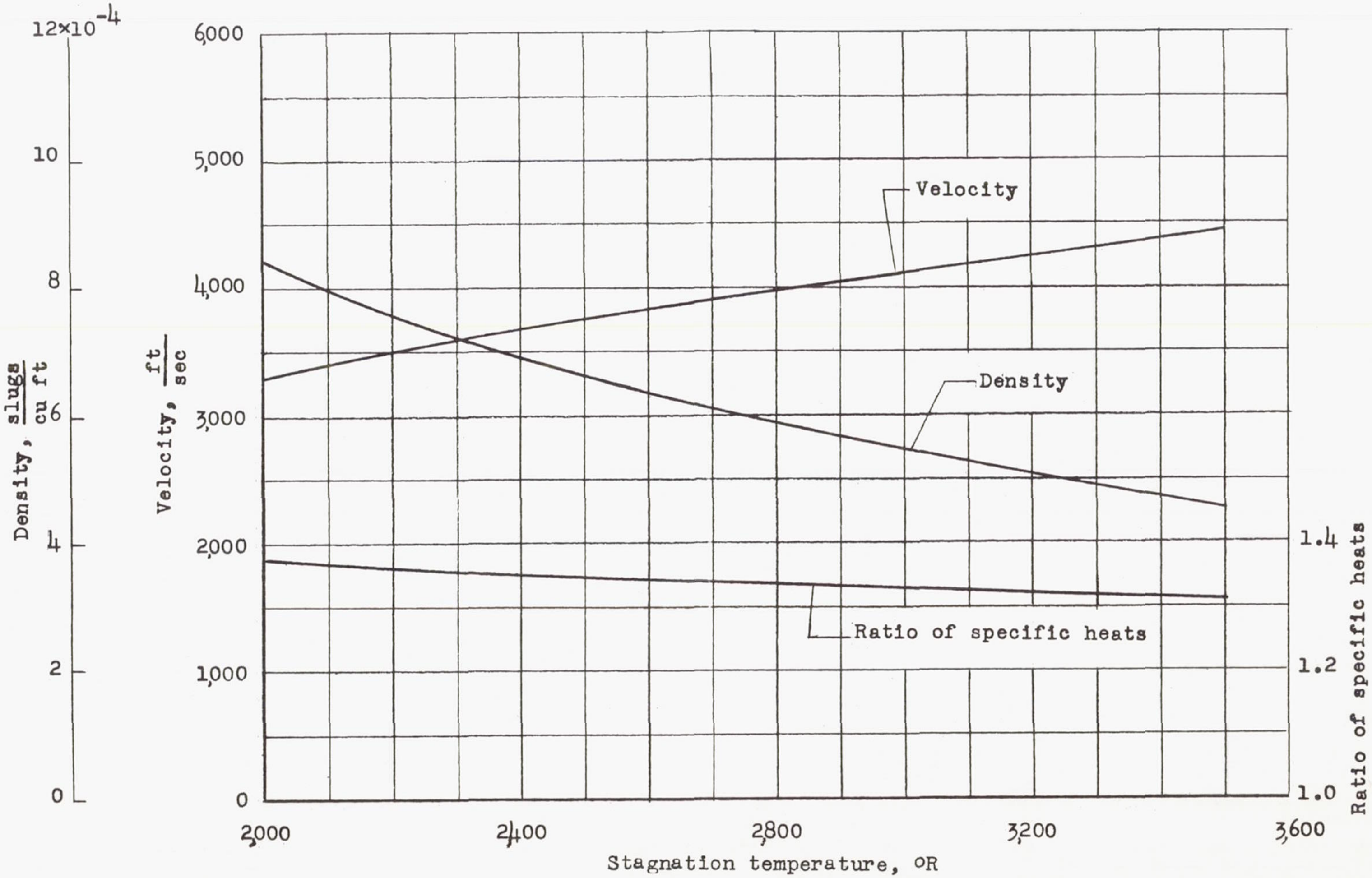



Figure 1.- Sketch of models. All dimensions are in inches.




(a) Velocity, density, and ratio of specific heats.

Figure 2.- Variation of stream conditions along jet center line with stagnation temperature.

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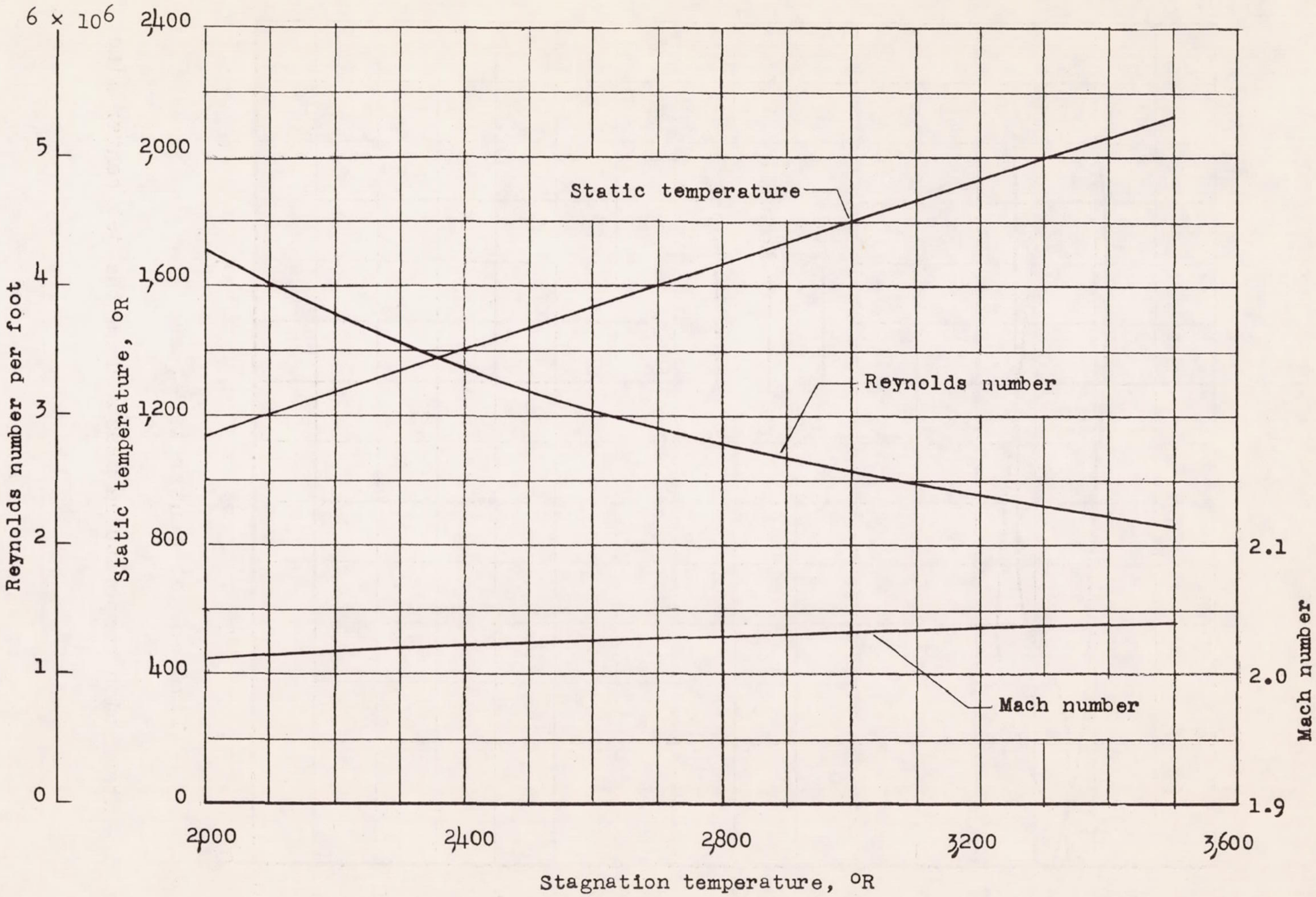



(b) Reynolds number based on a length of 1 foot, static temperature, and Mach number.

Figure 2.- Concluded.

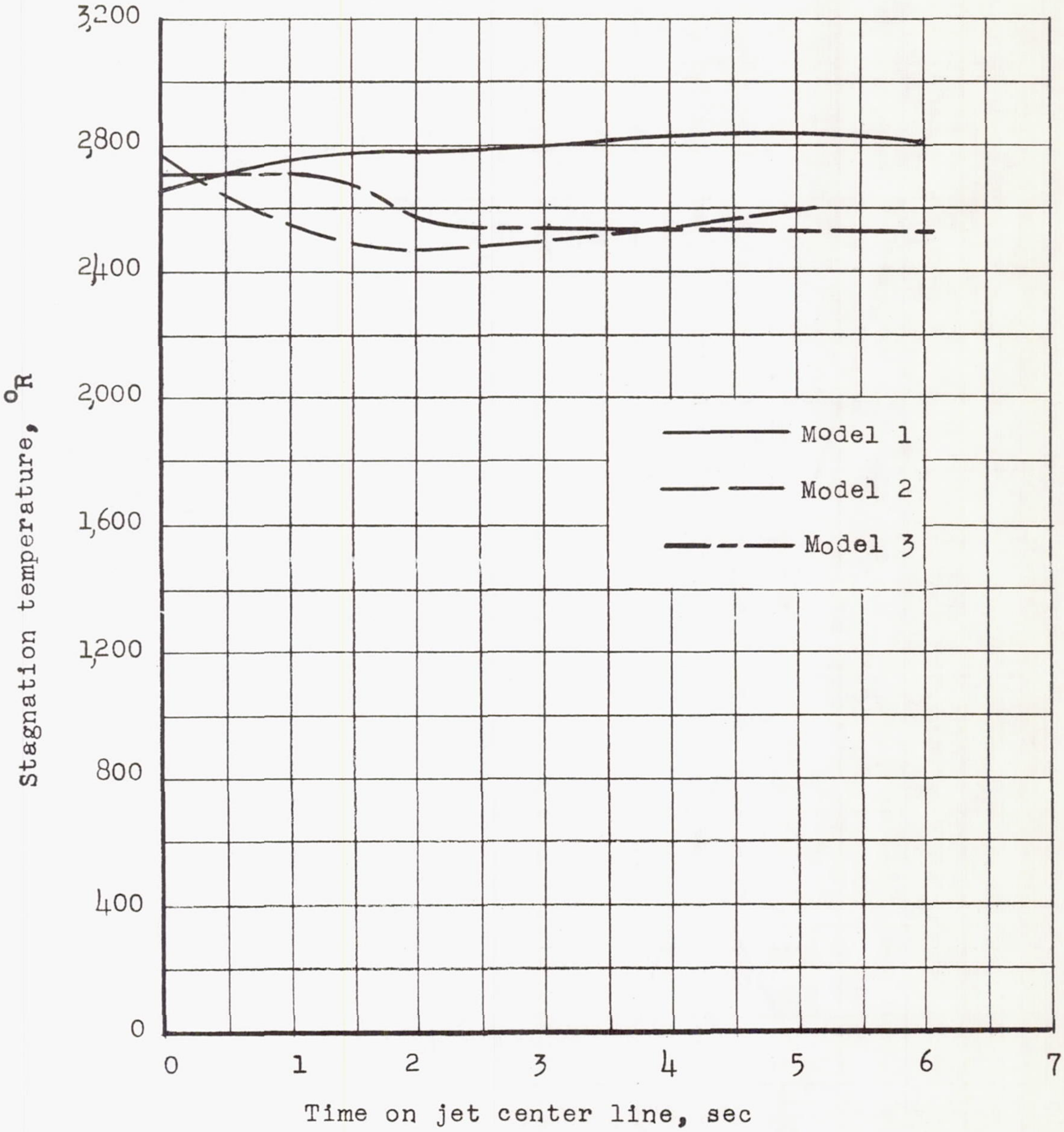



Figure 3.- Stagnation temperatures measured on the jet center line.

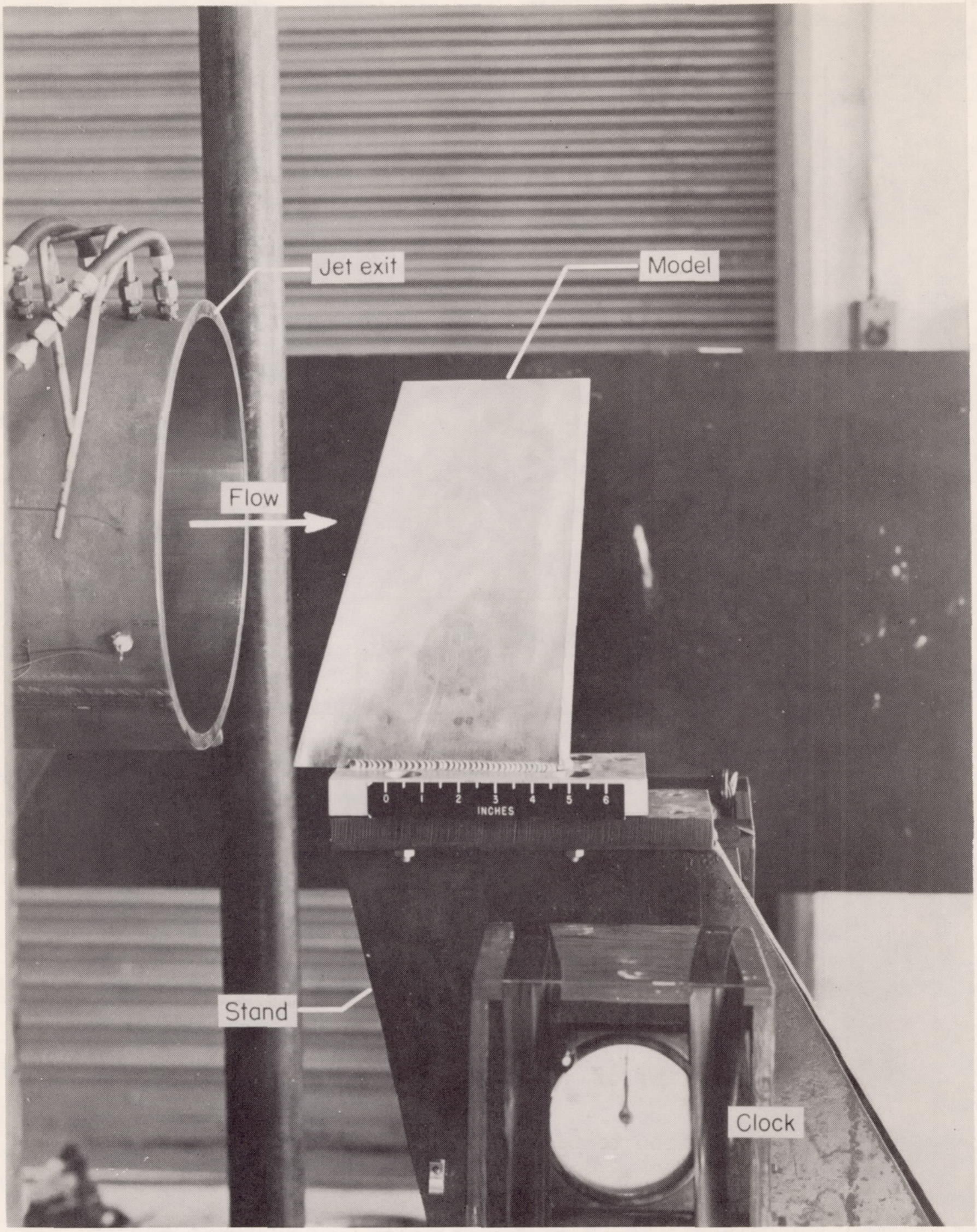
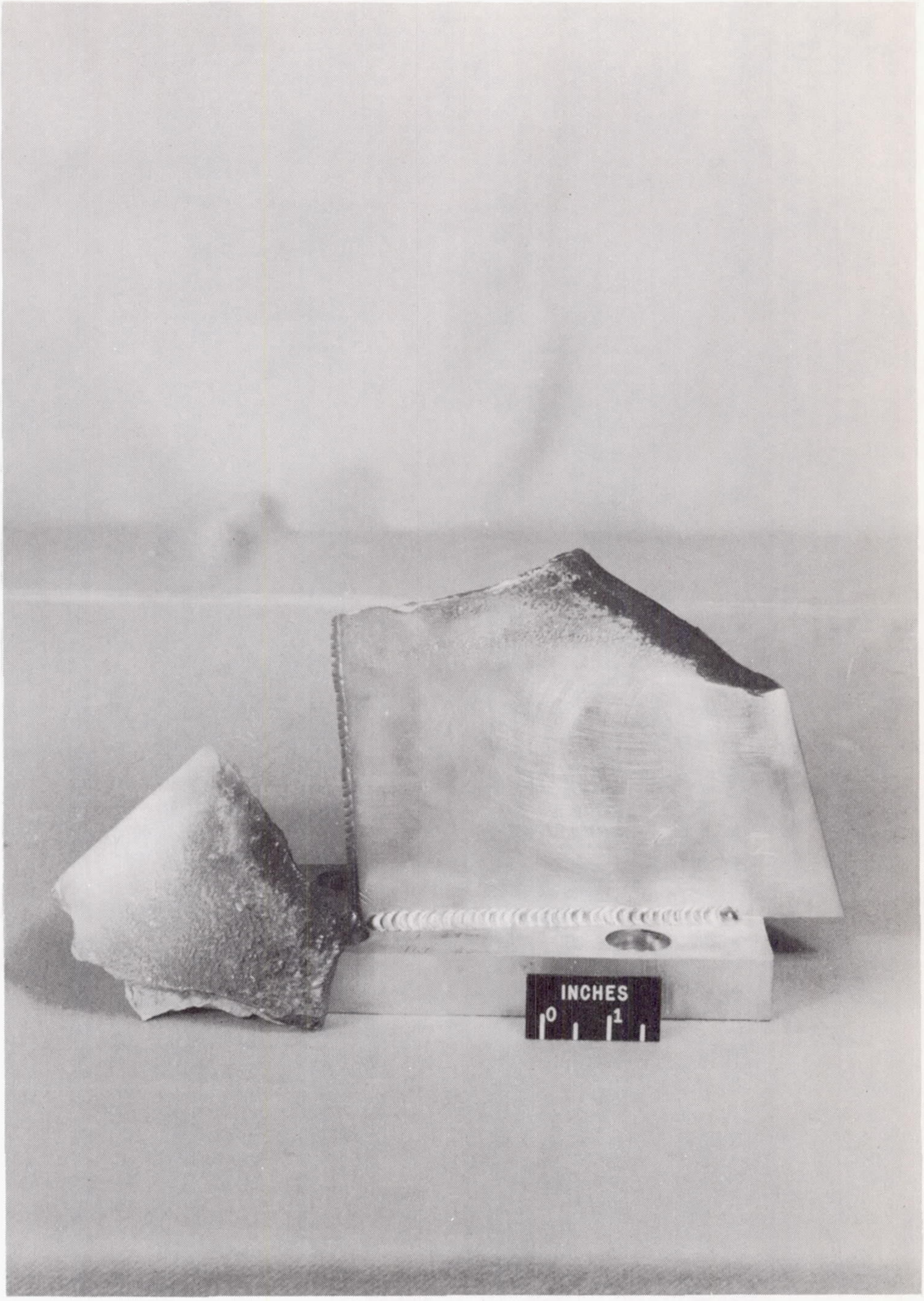
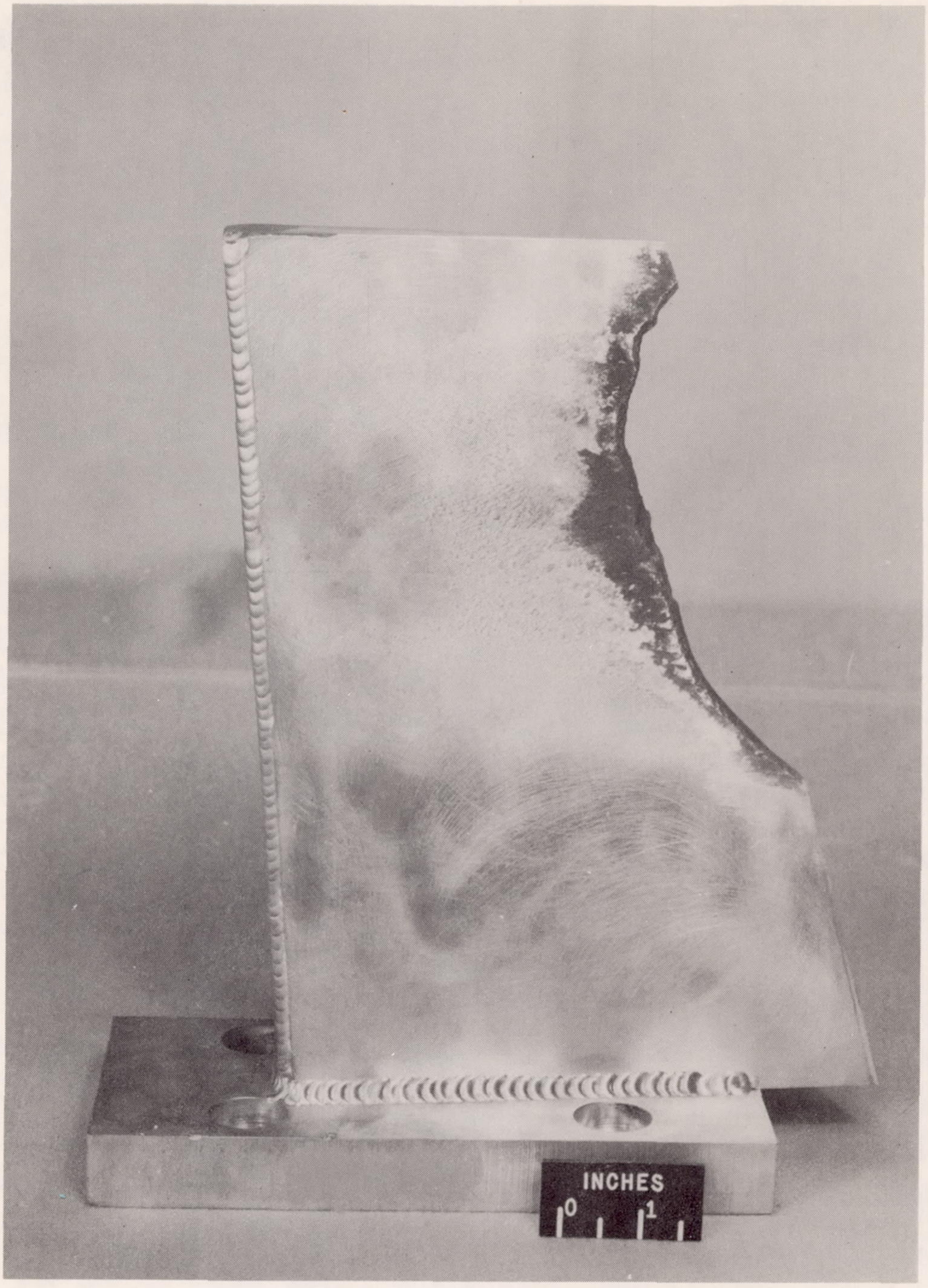



Figure 4.- Model 1 in testing position. L-94730.1



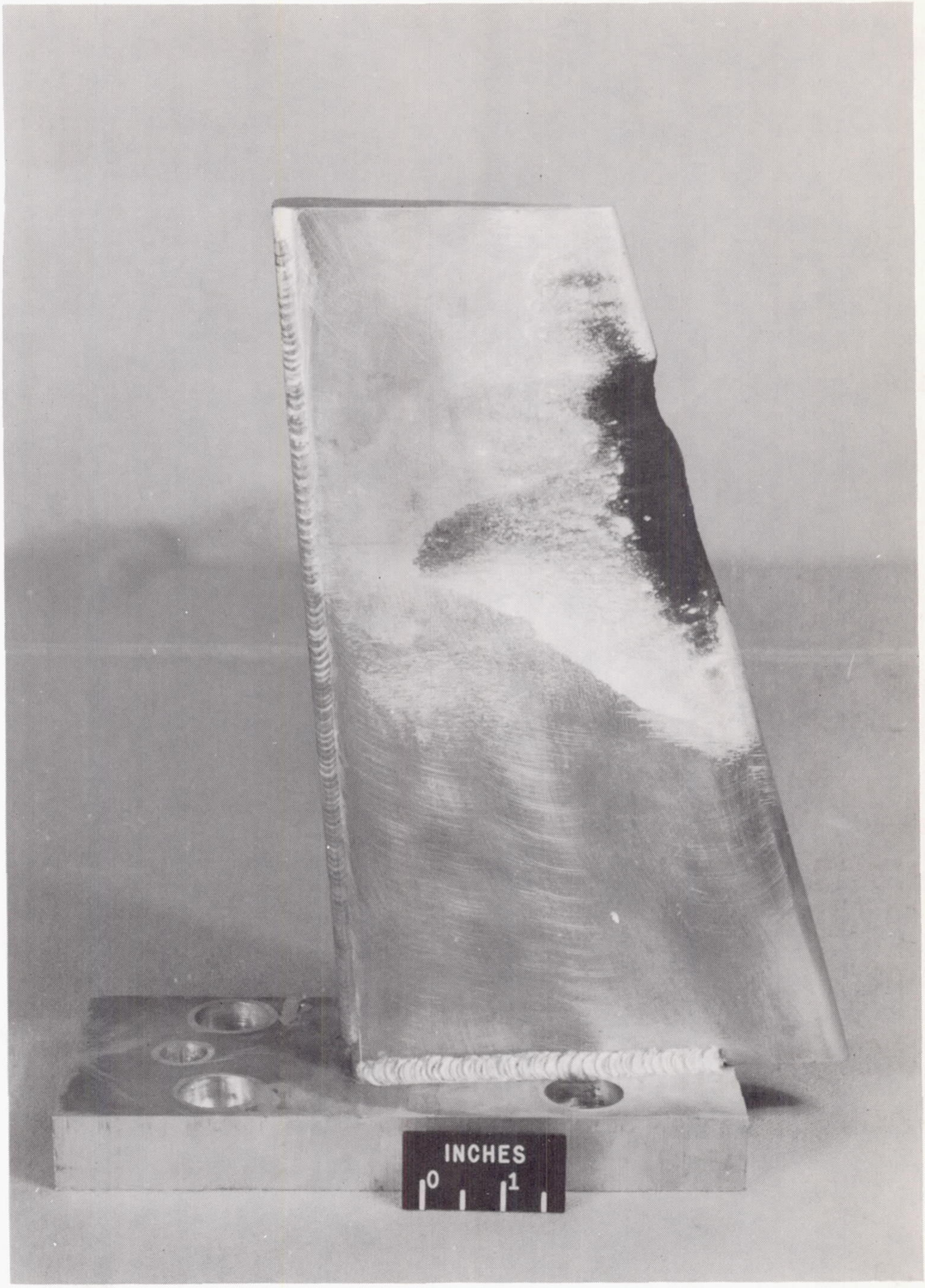

(a) Model 1 after exposure in the jet for 5.63 seconds. L-94604.1

Figure 5.- Damage to the models after testing in the jet.




(b) Model 2 after exposure in the jet for 5.14 seconds. L-94605.1

Figure 5.- Continued.




(c) Model 3 after exposure in the jet for 6.09 seconds. L-94608.1

Figure 5.- Concluded.

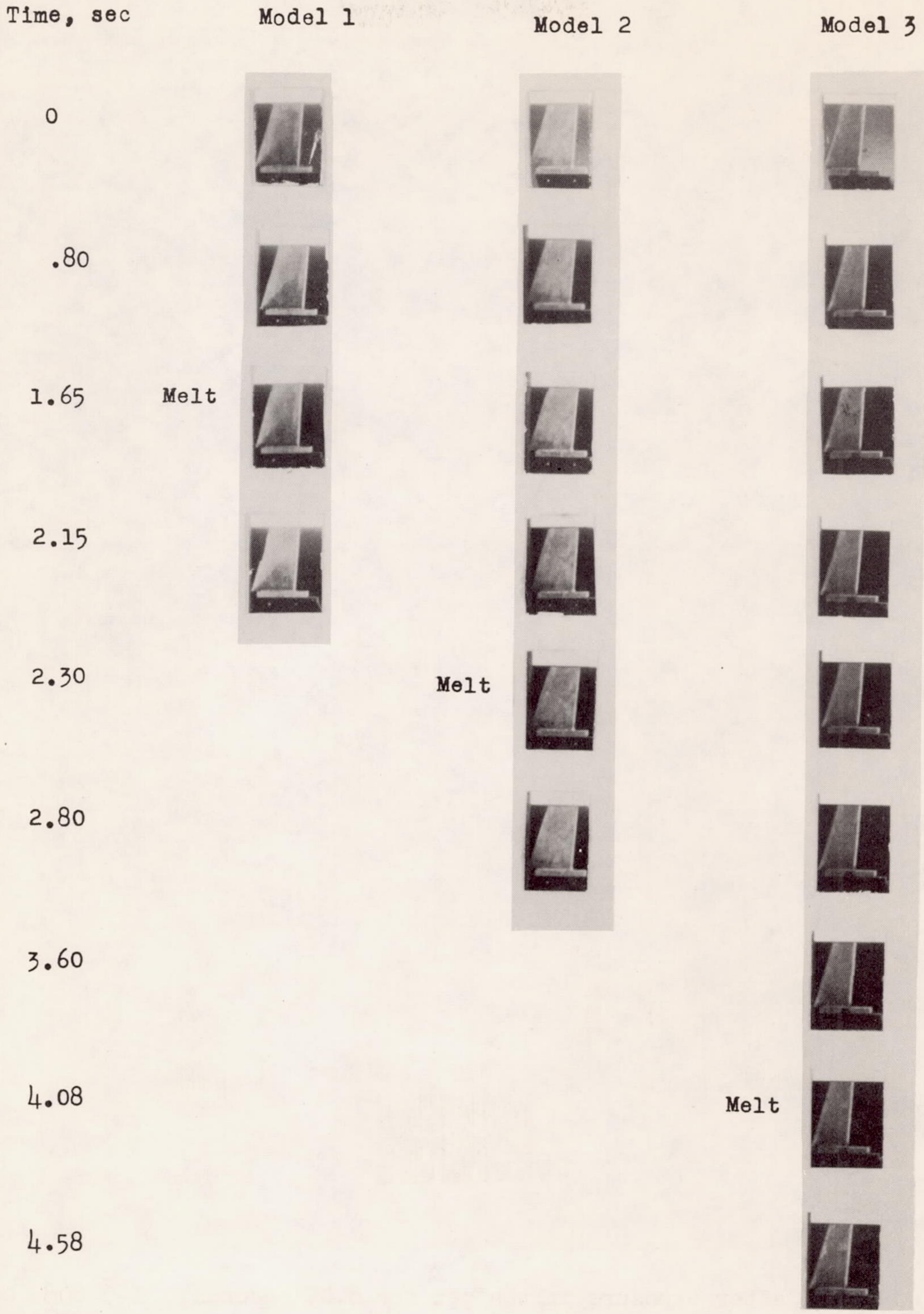



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Figure 6.- Results of tests as obtained from motion picture films.



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